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FORESTS DISEASES IN CALIFORNIA

problems and the research program of the Pacific Southwest Station

H. R. Offord

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FOREST DISEASES IN CALIFORNIA

Problems and the Research Program of the Pacific Southwest Station

By

H. R. Offord, Plant Pathologist

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U.S. DEPARTMENT OF AGRICULTURE, FOREST SERVICE
PACIFIC SOUTHWEST FOREST AND RANGE EXPERIMENT STATION
Berkeley, California

FOREWORD

At appropriate intervals research leaders at the Station review their projects to make sure that priorities and emphasis are in accord with the needs of resource managers. Such a job has just been completed for forest disease problems in California. The complete program analysis has been revised and greatly condensed and is presented here as a reference for foresters and for advisory groups.

Here under one cover are highlights of 50 years of experience with forest disease problems in California--a summary of key problems that are important in the protection of California's forest lands. This report also brings up-to-date an appraisal of suggested priorities, personnel, facilities, cooperation, and future needs for disease research. A list of selected references is given for work bearing directly on California problems.

There is a sound economic basis for an aggressive and forward looking program of disease research. Fungi, mistletoes, and physiological disorders take a steady but usually unspectacular toll of the timber resource in all forest types of the State from the time of seed collection to the logging operation. Roots, main stems, twigs, foliage, or seeds may be the object of attack. These disorders reduce growth, kill directly, or condition plants to damage by other pests or by physiological agents. They degrade and decay forest products from the woods to the pulp mill or the building. Surveys in the principal softwoods estimate the total disease impact (growth loss plus mortality) at 32 percent of the net annual growth in the State--and we have not yet had to face up to a major forest disease epidemic.

The goals of forest disease research are to prevent or to minimize these losses by predicting the course of disease development and devising economic methods of maintaining healthy, fast-growing forests. This review is intended to help researchers and forest managers achieve these goals through better planning of research and through a fuller appreciation of disease control problems.

FOREST DISEASES IN CALIFORNIA

Problems and the Research Program of the Pacific Southwest Station

By
H. R. Offord

PROGRAM RESPONSIBILITIES AND OBJECTIVES

The Pacific Southwest Forest and Range Experiment Station has responsibility in the Station territory of California and Hawaii to obtain and make known information on:

1. The identity, prevalence, behavior, and life cycle of disease pests, defects, and noninfectious disorders of forest vegetation.
2. The effects of decay and stains in forest products.
3. The significance of disease pests in timber management plans and in multiple use forestry.
4. The potential of foreign diseases for damaging wildland resources.

The present forest disease research program meets these responsibilities through statewide detection and appraisal surveys[1], through research on the ecology and biology of disease pests and disorders, and through testing and improving cultural, chemical, biological, and genetic methods of control. By these activities Station pathologists help to improve the protection of existing resources, restore nonproductive lands to efficient levels of use, and extend the useful life of forest products.

These program responsibilities and objectives are satisfactorily met only when research findings help the forester make decisions on management problems. We must be able to predict the behavior and impact of disease pests. It is not enough to have a "post facto" explanation for a disease epidemic. Well managed and closely utilized forests will minimize losses from endemic diseases and should reduce the economic impact of epidemics. But we need to know a great deal more about the situations wherein predictable and minor endemic losses become epidemic and catastrophic.

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[1] Effective July 1, 1961, detection and appraisal surveys were transferred from Research to National Forest administration. This intra-Service change in line responsibility for the conduct of survey work does not affect its significance to the research program.

The early performance of a parasite in various local environments often indicates how serious it will be in future years. Much of California, fortunately, is blessed with a warm dry summer, which reduces the risk of many types of disease epidemics. But we are vulnerable to attritional losses and to sporadic outbreaks triggered by extremes of weather. Disease may get its start in the disturbance of the normal functioning of the plant by some external factor. Heat, drought, frost, wind, dust, smoke, smog, etc., may kill quickly and directly or slowly and indirectly by means difficult to detect. Forest stands that are under adverse and continuous tension created by nonpathogenic agents may be damaged by endemic pathogens that normally have little effect on vigorous vegetation. Heat and smoke of forest fires and air pollutants may condition trees to damage by disease pests. The full effects of sublethal dosages of pollutants and of such agents as drought, frost, or overly wet soils may be long delayed and difficult to measure. This situation for diseases is in sharp contrast to that for fire and insects where the time lag between cause and effect is short and the primary cause of damage is obvious.

The ecology of fungi and insects and the physiology of the host must be better understood before pathologists can give the forester the guidelines that he needs to make decisions on species, density of stocking, thinning, and harvest age and on related silvicultural practices. Some notable examples of unpredicted disorders that have seriously disrupted management plans are: "X" disease of ponderosa pine in southern California and, in other forest areas of this country, pole blight of western white pine, birch dieback, needle disease of eastern white pine, sweetgum blight and sugar maple blight. Research must plan ahead and act aggressively to cope with such problems successfully. We can expect more rather than fewer of these threats to develop as virgin stands are cut and new ones are developed by natural regeneration or by planting.

The status and needs of forest disease research and control studies in California have been defined in several reports prepared over the past 35 years. In 1926 E. P. Meinecke reviewed all phases of basic and applied pathology for specific types of diseases, for host trees, and for the forest stand (8)[2]. W. W. Wagener in 1955 reported on forest disease problems in the California region, giving attention to ten broad classes of diseases which he discussed as to their significance and potential, status of knowledge, ecological and silvicultural aspects, genetic and sanitative aspects, and research needs (10). Wagener's report has been used freely in presenting the present highlights of the character and behavior of California's disease pests. The status and needs of blister rust control investigations were outlined in a Forest Service report by H. R. Offord in 1954 (9); a similar report was prepared for the Bureau of Entomology and Plant Quarantine in 1949. Administrative guidelines for forest disease control and brief descriptions of California's principal disease pests are contained in Chapter VI of the Timber Management Handbook for Region 5 (4). Disease problems, their priorities, and the scope and intensity of research effort recommended by Station pathologists and by advisory and participating agencies are briefly set forth in: the 1956 CORE report to the Department of Agriculture (2), the California Forest Pest Control Action Council report of 1954 on the insect and disease pests of California forests (1), and the 1958 Wildland Research Plan for California (7).

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[2] Underlined numbers in parentheses refer to citations in the list of publications.

These reports are in agreement that the present disease research program covers just about half of the recognized and immediate needs and that deferred needs and desirable expansion within the next 10 years would increase the level of activity about threefold. At present the efforts of eight Station pathologists are directed to problems on 42.5 million acres of forest land in California--about 5.3 million acres per man.

VALUES AT STAKE

Diseases threaten and may disrupt the orderly and planned use of wildland resources on 42.5 million acres of forest land in California. This impact is most direct and clearly recognized in the management and protection of 17.3 million acres of commercial forest land. Diseases kill trees or reduce their growth rate, curtail seed crops, and degrade the value of forest products. A sick and nonproductive tree can be worse than a dead one because it occupies valuable forest space for a long time to no useful purpose, and because it may contribute to further spread of disease. Some diseases work underground where their presence is hard to detect. Others work so slowly that foresters are often unaware of their seriousness and defer control action until forest stands have stagnated or been damaged and valuable growing time has been lost.

The first overall appraisal of disease losses in California forests was made as part of the national report in the Timber Resource Review (6). The growth loss in live sawtimber from major disease pests in California is estimated at 930 million board feet per year; in addition, about 200 million board feet of softwood sawtimber is killed each year. These estimates do not include the mortality and growth loss in trees below 5 inches in diameter (breast high). Annual growth impact in these smaller trees is about 192 million cubic feet.

The annual growth loss in softwood sawtimber can be charged against four classes of disease pests as follows:

	Million board feet
Heart rots	350
Mistletoes	200
Stem rusts	200
Root and foliage diseases	180
Total	930

These are conservative estimates. Root disease losses undoubtedly greatly exceed the 180 million shown above for root and foliage diseases combined. The total represents 32 percent of the estimated 2.9 billion board feet of net annual growth from 17.3 million acres of California's commercial forest land. Or it may be measured against California's 1956 lumber production of 5.9 billion board feet. Losses of this magnitude cannot be tolerated in an era of costly intensive management.

Frost, snow, wind, drought, and lightning cause direct losses of growing stock and merchantable trees and contribute to degrade in the quality of lumber and other wood products. Damage from these agents accelerates destructive action of fungi that would not otherwise be serious in vigorous stands. Trees with root systems weakened by disease are susceptible to windthrow. Stain, incipient decay, checking, frost crack, and pitch pockets increase the cost of manufacturing wood and wood products by amounts that are difficult to measure. In the aggregate, damage from noninfectious causes (excluding animal damage) may be as great as that from disease, but no reliable estimates of such losses are now available.

Diseases of hardwoods, browse plants, and grasses of wildland areas have received little attention from forest pathologists in California. No estimates have ever been made of disease losses in these categories. The disease survey is directed chiefly to commercial timber lands. Wildland vegetation other than conifers must certainly receive attention commensurate with its value in watershed, range, recreation, and wildlife uses. Management and protection in high use recreation areas will be difficult and costly unless the forest cover is kept vigorous and free of disease.

Products pathology, which includes stains in logs, lumber, pulpwood, and decay of structural wood in use as well as the preservation of these products has limited coverage in this program analysis. Except for consultation on local problems of wood in use and stains in logs and lumber, products pathology is the primary responsibility of the Forest Products Laboratory insofar as the Forest Service is concerned. Nevertheless we are concerned about the degrading of lumber and the deterioration of wood in use which add up to large but indeterminate financial loss every year.

REGIONAL VARIATIONS IN DISEASE PREVALENCE

Climate, soils, and vegetation of California's wildlands vary greatly from the Pacific Coast to the crest of the Sierra Nevada and from south to north. We see tremendous contrast, for example, between the cool, humid conditions of the extreme northwest, where seasonal and diurnal temperature changes are modest, and the dry east side conditions of southern California, where these changes are tremendous. Aside from host specificity and biologic competition, the important factors limiting the prevalence and vigor of disease pests are the duration of critical levels of temperature and moisture and the pH and aeration of soils. These general considerations suggest that disease problems of the present and foreseeable future will have varying impacts on the timber resources of the State in the several recognized timber types and subregions.

Five subregions which are generally accepted for land classification purposes in California (see map) and which constitute significantly different regimes of climate and vegetation are:

1. Southern California--mixed conifer.
2. Westside Sierra Nevada--mixed conifer.
3. Eastside Sierra Nevada--ponderosa, Jeffrey.
4. North Coast--redwood, Douglas-fir.
5. Coast Range--ponderosa, Douglas-fir, true firs.

Differences among these subregions are reflected in the impact of major disease problems.

HEART ROTS

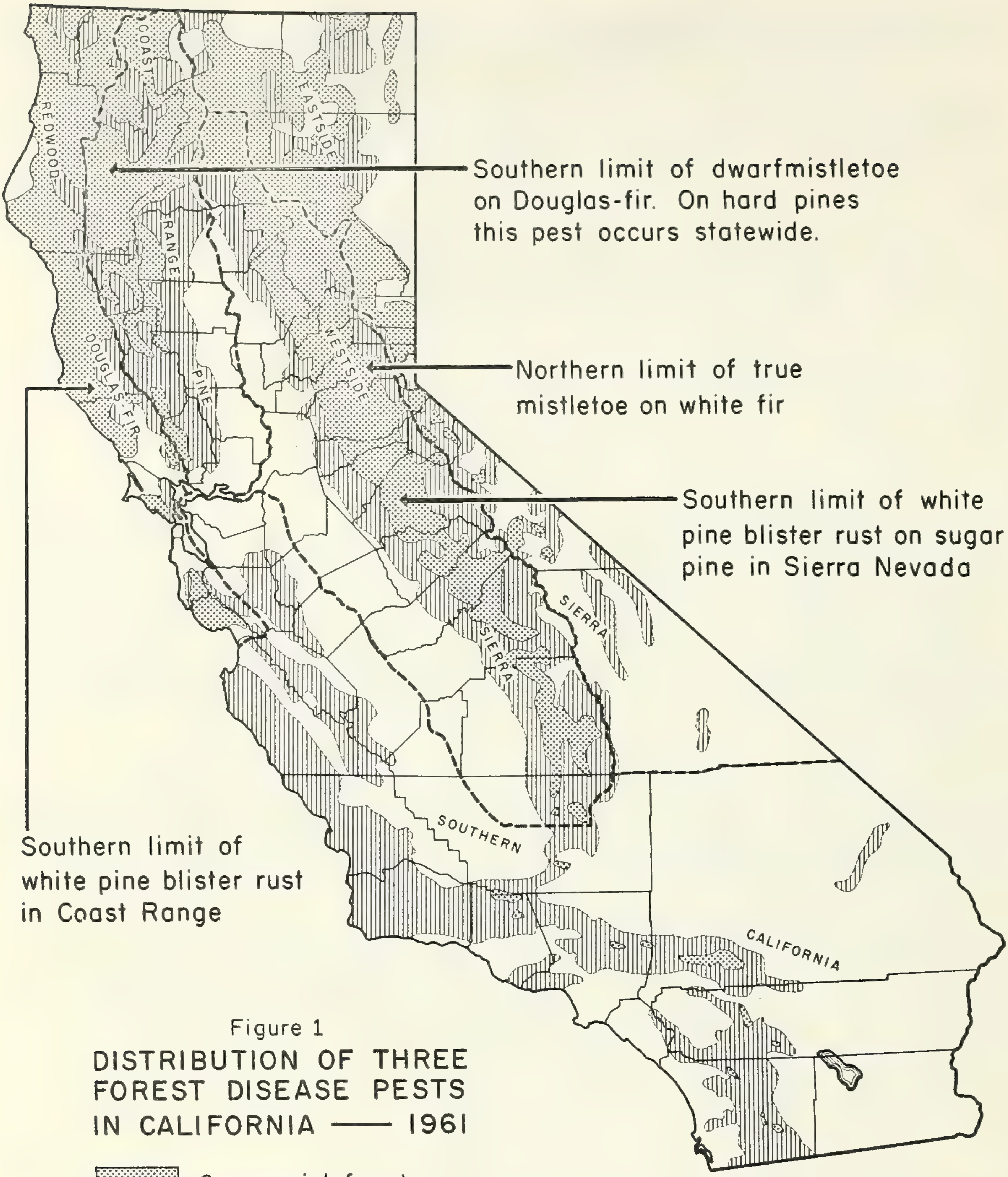
Fomes pini, which accounts for the greatest volume of decay because of its prevalence in Douglas-fir, is most active in the inner North Coast and the Coast Range subregions. Pocket dry rot (Polyporus amarus), which causes an average 36 percent cull decay in incense-cedar, is about three times more prevalent under westside than under the drier eastside Sierra Nevada conditions. In old-growth stands of redwood, cull percentage (of gross cubic foot volume)--caused chiefly by Poria sequoiae and P. albipellucida--ranges from 19 percent in Sonoma County in the south to 34 percent in Del Norte, the northernmost coast county.

Indian paint fungus (Echinodontium tinctorium) in white fir increases in prevalence from south to north in the State. Also, growth rate is greater for northern than for southern isolates of the fungus. Indicator cull factors developed for white and red fir in northwestern California apply equally well to these two species in the Sierra Nevada.

Largely because of dry summers that prevail throughout ponderosa pine types of California, red ray rot (Polyporus anceps) is rare on living trees. As a heart rot it is found most often in the northeastern part of the State. Elsewhere it is a slash decayer of intermittent distribution. In the southern Rocky Mountain region, however, where summer rains occur P. anceps is virulent on living ponderosa pine and may cause 30 percent or more cull decay.

MISTLETOES

The true mistletoe (Phorandendron pauciflorum) on white fir is aggressive and occurs abundantly in southern California and in the southern Sierra Nevada. This pest has not yet been found north of Placer County in central California. Temperature probably limits its northward extension.



Southern limit of dwarfmistletoe on Douglas-fir. On hard pines this pest occurs statewide.

Northern limit of true mistletoe on white fir

Southern limit of white pine blister rust on sugar pine in Sierra Nevada

Southern limit of white pine blister rust in Coast Range

Figure 1

DISTRIBUTION OF THREE FOREST DISEASE PESTS IN CALIFORNIA —— 1961

▒ Commercial forest

▥ Noncommercial forest

☐ Nonforest

---- Subregion boundary

Dwarfmistletoe (*Arceuthobium campylopodum*) has virtually statewide distribution on the hard pines. It is a much more serious pest on poor sites of the eastside Sierra Nevada and in southern California than in good sites on the westside Sierra Nevada. In contrast, dwarfmistletoes on red fir, white fir, and sugar pine do not follow any special site pattern. On red and white fir, dwarfmistletoe is widely distributed on all sites where the species is a major component of the stand. On sugar pine, dwarfmistletoe is patchy in distribution but may reach its most damaging level in Sites I and II. Dwarfmistletoe (*Arceuthobium douglasii*) on Douglas-fir is confined to inner mountain areas of northern California; it occurs rarely if at all in coastal areas, and has not been found any farther south than a mid-latitude in Trinity County. Lodgepole pine dwarfmistletoe (*Arceuthobium americanum*) is common on the mountain form of lodgepole pine but seldom attacks the coast form.

STEM RUSTS

White pine blister rust (*Cronartium ribicola*), a disease of foreign origin, attacks sugar pine and other white pines. Natural environmental factors aided by direct control have so far held this pathogen to the line of the Stanislaus River in its southward spread down the west side of the Sierra Nevada. In the Coast Range the most southerly known infection is at Gualala Lookout in Mendocino County. Generally the virulence of blister rust decreases as one moves southward from the Oregon line to the central part of the State.

Local climate, and land use that stimulates growth of host plants, can strongly influence the intensification of some native stem rusts. For example, ribes must be closely associated with pinyon pine in a favorable regime of moisture and temperature before pinyon rust (*Cronartium occidentale*) becomes epidemic; similarly, concentration of bastard toad flax is needed to trigger outbreaks of comandra rust (*C. comandrae*). Western gall rust of the hard pines (*Peridermium harknessii*) will be most troublesome in localities where high humidity and cool temperatures prevail and where there are even-age young stands or plantations. Gall rust can be especially destructive in nurseries.

ROOT DISEASES

Damping-off fungi and root rots of 1- and 2-year-old seedlings and transplants can be troublesome problems in forest nurseries. Fortunately, these pests can be contained under nursery conditions by cultural and protective measures that moderate or control soil temperature, moisture, aeration, and pH in seed and transplant beds, including the timely use of fungicides. For many forest nurseries of California the most serious threats will come from root diseases (*Sclerotium* sp. and *Fusarium* sp.) that are favored by high temperature. Virulent pathogens such as *Phytophthora* spp. are rapid killers of nursery seedlings and present a threat to the planting program if infected nursery stock is moved from nursery to the forest.

The most damaging root disease now established and native to forest areas of California is Fomes annosus Mortality from this disease is greatest in southern California and in the eastside Sierra Nevada, where alternations of long periods of drought with occasional wet years reduce the vigor of the trees and accelerate epidemic development of the pathogen. On the basis of experience in Europe and the southeastern United States, we can expect that thinnings in managed stands of the future are certain to make F. annosus a pest of increasing importance.

Verticicladiella sp. is also an aggressive pathogen in restricted areas. One form attacks pinyon pine in southern California and another, ponderosa and Jeffrey pines in eastside Lassen and Modoc Counties. Armillaria mellea is most prevalent and active in conifer-oak types and causes sporadic and scattered damage statewide in California. Young sugar pines are highly susceptible to this root disease. The extension of forest plantings into former oak or oak-conifer sites by development of small woodlots could materially change the present minor role of A. mellea.

FOLIAGE DISEASES

Elytroderma needle blight (Elytroderma deformans) attacks hard pines throughout the State and is especially damaging to ponderosa and Jeffrey pine in canyon bottoms and cool flats bordering lakes. Infections that persist in localized areas are serious and can be readily identified by the presence of heavily broomed branches and by damage to the tree crown. The pathogen is not often virulent in the lower elevation range of ponderosa pine. Hypodermella medusa is widely distributed on pines but has been of concern to forest managers only in the pure pine stands of northeastern California. Even here the attack seems to be limited to a highly susceptible portion of the stand. The infective capacity of rhabdocline needle cast of Douglas-fir (Rhabdocline pseudotsugae) and other foliage diseases of the true firs vary with the abundance of moisture from year to year. The impact of these foliage diseases on Douglas-fir and true firs is greatest on small trees used in the Christmas tree trade.

Foliage diseases of hardwoods--notably those attacking California black oak, tanoak, sycamore, madrone, and California laurel--and the damage that they cause also vary considerably with micro and macroclimate. Accumulated observations on the ecology of these foliage diseases and their potential in the several forest regions of the State will be of value when hardwood species are brought under intensive management.

FOREIGN DISEASES

During the past 50 years all but a small portion of the money appropriated by public agencies for direct control of forest diseases in the United States has been spent for the control of three foreign or introduced diseases: white pine blister rust (Cronartium ribicola), chestnut blight (Endothia parasitica), and Dutch elm disease (Ceratocystis ulmi).

Blister rust, which spread into northern California about 1930, is the only foreign disease that constitutes an immediate threat to California's forests. Since 1934 blighted chestnuts were located and destroyed at six places in California, including one close to the Institute of Forest Genetics. California chinkapins are susceptible to this disease, but climatic conditions of the State appear to be unfavorable for its spread. Dutch elm disease has not yet been found in California.

There are three lines of defense against the introduction of forest disease pests and their potentially tragic impact on wildland resources. They are: quarantines and inspection to prevent or restrict the importation of living host plants, the protective treatment of all imported seed, and research at home and abroad on the biology of dangerous pests. Work with exotic vegetation should be restricted to properly treated seed and should not involve the importation of plants or soil. Wood, and wood fibre used as packaging materials for international shipments, present a continuous threat. It is difficult to devise reliable safeguards against entrance of such raw materials. Nevertheless, quarantines serve valuable purposes. They do intercept a high percentage of undesirable material and they provide delaying action to buy us time for developing control methods.

Research pathologists in this country have long recognized the importance of keeping records on diseases of foreign trees growing in the United States and of North American trees planted abroad. Two U.S. Department of Agriculture handbooks of international interest listing tree hosts and known diseases were published in 1956 and 1958 (55, 56). One additional handbook in this series prepared by Department pathologists is now ready for publication. It will describe foreign infectious diseases and their potential for damage. Through cooperation in International Union Forest Research Organization, the exchange visits of forest pathologists, and through constant study of the world's literature, we can be forewarned and be better equipped to deal with diseases of foreign origin. Buchanan (18) gives a useful summary of the threat of foreign diseases to North American forestry.

WHAT HAS BEEN DONE

Forest disease research in California was started in 1910 by pathologists of the Bureau of Plant Industry (after 1933 the Bureau of Plant Industry, Soils, and Agricultural Engineering) and continued under this agency of the U.S. Department of Agriculture until 1953. Blister rust survey and control studies were conducted by pathologists and foresters of the Bureau of Plant Industry (1919-1933) and the Bureau of Entomology and Plant Quarantine (1934-1953). Research and control studies of these two Department agencies were transferred to the Forest Service in 1953 and 3 years later were combined as activities of the Division of Forest Disease Research in the California (now Pacific Southwest) Forest and Range Experiment Station.

From the beginning these research and control investigations were carried out by Department of Agriculture personnel in close collaboration with the Department of Interior and other federal agencies responsible for the management and protection of public land. Equally close cooperation was maintained with state, university, and industrial leaders in forest administration and research. For California this cooperation among the State Division of Forestry, the University of California, and the Forest Service is clearly expressed by the preparation and publication of two reports (7) "Wildland Research in California" and "Wildland Research Plan for California." A development of signal importance to forest disease research in California occurred in 1957 when the University of California established a full time teaching position in forest pathology in the Department of Plant Pathology at Berkeley.

Fifty years of research, survey, and control studies in California have contributed impressively to the science of forest pathology, to the handbooks of forest managers, and to the needs of users of forests and forest products. An herbarium of forest tree diseases of California has been developed and is being maintained in the Pacific Southwest Station at Berkeley. The references given in this report give details of the following major accomplishments:

¶ Diseases of major importance in California's wildlands and nurseries have been studied in the field and laboratory, and their damage potential has been appraised through pest conditions reports and special program reports. (1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 35, 36, 39, 40, 42, 61)

¶ A disease survey on permanent sample plots was started under pest control support in 1956. In 1958 the survey methods were revised so as to sample commercial timber types of the State in a random and unbiased fashion. In 3 years of use, this system has furnished data on 290 plots. Special intensive and extensive survey methods have been designed and used for white pine blister rust and dwarfmistletoe control. Since the survey program was activated in 1956, the following diseases have been found for the first time in California: A rust (*Coleosporium jonesii* (PK)) on the needles of pinyon pine; a true mistletoe *Phoradendron* sp. on golden chinkapin; and fruiting bodies of *Rhizosphaera pini* (Cda.) Maubl., on needles of sugar pine. This seems to be the first time that *Rhizosphaera pini* has been found on sugar pine or in California. For details see annual reports on "Pest Conditions in California" 1956 to 1960 inclusive (3).

¶ Studies on rate of deterioration and disappearance of logging slash in westside Sierra Nevada mixed conifer stands and in eastside Sierra Nevada ponderosa pine were started 30 years ago and are now being completed for publication.

¶ Guidelines have been written for predicting the survival of fire-swept timber and reports prepared on the impact of cold and drought on forest stands. (38, 44, 58, 64, 65, 66)

¶ Principal decay fungi and stains responsible for deterioration of fire-killed timber in California have been studied and rated according to their importance in producing characteristic defects of sapwood and heartwood. White fir, Douglas-fir, sugar pine, ponderosa pine, and Jeffrey pine were included in these quantitative ratings (25).

¶ Nursery diseases have been noted, identified, and control measures recommended (4, 5, 10, 45).

¶ Foliage diseases of hardwoods and softwoods have been followed through epidemic and endemic stages and their impact on tree hosts assessed (11, 32, 33, 35, 68, 71).

¶ The important heart rots of California's principal conifers have been described. Their prevalence and mode of entry into the living tree have been studied. Cull factors have been determined for coast redwood, Douglas-fir, red fir, and white fir in the North Coast and Sierra Nevada. Flat cull factors were derived for ponderosa and sugar pine and for incense-cedar. Breakage factors have been estimated for pines, incense-cedar, and redwood. Temperature effects on the growth rate of the Indian paint fungus have been determined for several strains of the fungus collected from central and northern California (16, 20, 23, 24, 27, 28, 29, 30, 44, 58, 60, 69, 72).

¶ Over a period of 30 years, development and improvement of methods for the control of white pine blister rust have been worked out jointly with federal, state, university, and private forest researchers and forest managers. Findings that have been widely used in the field and projects on which substantial progress has been made include: influence of edaphic and climatic factors on the distance of spread and virulence of the rust under various site conditions; the development of chemicals, equipment, and methods for the control of ribes; testing of fungicides for preventing or controlling infection on pine and on ribes; ecolcgical control of ribes including seed germination studies; selection and propagation of rust resistant sugar pine; field methods for locating and measuring ribes population; delineation of pine areas as management units; and analysis of economics of sugar pine management-blister rust control (12, 13, 14, 19, 22, 30, 43, 45, 46, 47, 48, 49, 50, 52, 53, 54, 57).

¶ Dwarfmistletoe survey, research, and control studies have combined to give us a fund of information applicable in silvicultural control. Artificial seeding tests of dwarfmistletoe in different parts of the pine types, anatomy of the parasite, host specificity in the true firs, seed germination studies, field tests of chemicals for the direct control of the pest have been the primary objectives of the research effort in California. The effect of cold on the distribution of the leafy mistletoes has been studied. The status and needs of research on dwarfmistletoes have been defined (1, 2, 3, 4, 6, 7, 8, 10, 26, 35, 66).

J Coryneum canker of Monterey cypress in California was noted, studied, and described as *Coryneum cardinale* Wagener (Fungi imperfecti) (59, 62, 63). Stump sprouts and plantations of redwood in coastal areas have been seriously damaged by a coryneum fungus that apparently differs in host reaction from *Coryneum cardinale* (63). Sporadic outbreaks of three other cankers have been described. *Botryosphaeria ribes* was isolated from giant sequoia and several other hardwood and softwood species (51). *Cytospora abietis* a canker of true firs (73), and *Phomopsis lokoyae* of Douglas-fir (17) have shown accelerated development following periods of drought.

THE JOB AHEAD

The need to expand the base of our national wood resource (6) and to strengthen the competitive position of the wood industry places a high premium on the protection of forest growing stock. In both research and control activities the job ahead calls for a greatly expanded effort to keep pace with increased demands for wood products, for recreation and wildlife, and for water and animal products from all types of forest lands. We recognize that there will always be legitimate research needs far in excess of available facilities. Thus problems and priorities must be geared to the anticipated level of support. The Forest Service effort is and will continue to be strongly aided by cooperation with university, state, and private industry. In the ensuing pages of this section of the report, priority of problems in California is generally indicated by the order in which they are discussed. The present research effort is compared with that suggested by the national forestry research program for the Forest Service and by cooperating and advisory groups.

FACILITIES AND PERSONNEL

The Station's forest disease research staff, eight pathologists and a chief clerk, is headquartered at Berkeley, California, where excellent laboratory, library, and office facilities are available. The staff for 1961 is the same size as that of 1956. Laboratory space is adequate for six full-time researchers supported by two laboratory aids and intermittent student help, but some additional laboratory equipment is needed. Limited greenhouse space has been provided on an "as needed" basis through cooperative agreement with the University of California. The Division does not maintain a field laboratory but has access to the laboratory, greenhouse, and arboretum of the Institute of Forest Genetics, Placerville, California.

To meet our obligations at the level of research indicated by the 10-year program of the Forest Service, the present staff should be increased to about 13 research pathologists, who should be aided by several technicians for laboratory, field, and greenhouse work. Additional apparatus and special research tools such as microscopes needed for the expanded program are not itemized at this time. Adequate greenhouse space (about 1,000 square feet in two sections) with supporting headhouse area is a top priority need for any expanded program of research. The 10-year research plan would place 9 researchers (including the supervisory pathologist) at Berkeley on general problems, 2 at Placerville to develop disease-genetics studies, and 2 at Riverside to advance pathological aspects of research on the "soils--air pollutant--noninfectious disorders of forest stands."

Exclusive of clerical and special technical services, 96 man-months are now being devoted to the planning and conduct of research, detection survey, and control studies at the Station. Eight problem areas are receiving attention in the following order of priority and generally decreasing time allotments: white pine blister rust, detection surveys, mistletoes, nursery diseases, heart rots, genetic resistance, root diseases, unknown disorders including "X" disease of southern California.

By comparison with the present effort of 96 man-months which includes both research and survey, the 10-year Forest Service program suggests a level of 156 man-months for research alone. The California Wildland Research Plan (7) sets the recognized disease research and pest survey needs for all agencies at 273 man-months, of which 189 man-months are shown for combined "existing" and "additional high priority needs" and 84 man-months "deferred needs." Earlier recommendations by the California Forest Pest Control Action Council (1) were in substantial agreement with current Forest Service and State advisory groups about the importance of making substantial increases in disease research.

Since future detection and appraisal survey conducted by the Forest Service will be the responsibility of the Regional Office rather than the Station, present and suggested level of survey needs are in addition to those just noted for research and are shown separately as follows in man-months per year:

Present level at Pacific Southwest Station		18
Suggested level for 10-year Forest Service program		30
Needs of all agencies, Wildland Research Plan for California (7):		
Existing program	26	
Additional high priority needs	8	
Deferred needs	18	
Total recognized needs		52

COOPERATION

Immediate and continuous liaison is maintained between Station pathologists and entomologists and Federal, State, and private foresters on pest detection and appraisal surveys, control studies, and training of foresters in disease identification. For intrastation coordination of disease research, our most direct associations are with Forest Insect Research, Forest Management Research, Forest Genetics Research, and Forest Products Utilization Research.

Direct and frequent contacts with University of California faculty and graduate students provide strong and continuous support to our research on pathology and related problems of forest protection. Those most directly concerned are the School of Forestry and the Department of Plant Pathology at Berkeley and the Department of Botany at Davis and at Berkeley. By making funds available to graduate students in plant pathology and botany at the University, the Station started cooperative aid research on white pine blister rust and dwarfmistletoe. These cooperative aid agreements have not only resulted in valuable research findings, but have helped to train forest pathologists for career service and employment in the Forest Service. Station personnel also are working closely with Dr. Parmeter and his assistants in the Department of Plant Pathology at Berkeley on special aspects of the dwarfmistletoe and "X" disease problems now being aided by allotments from the State Division of Forestry.

On policy and general matters pertaining to disease research and forest protection, we work closely with the California Division of Forestry, the California Forest Pest Control Action Council, and with foresters of private industry. Control and regulatory personnel in the State Department of Agriculture have long worked with us in quarantine, disease, and noxious plant control. Research accomplishments are reviewed and personal contacts with forest pathologists maintained annually at a meeting (Western International Forest Disease Work Conference) of public and privately employed pathologists and foresters specializing in disease control work.

Through correspondence and exchange of publications, we enjoy close cooperation with the Centralia Research Center of the Weyerhaeuser Timber Company. The chemical industry has cooperated closely with our pathologists working on the chemical control of forest diseases. Research and development specialists in phytocides and fungicides consult with us and inspect results of field tests. These contacts have been chiefly with Amchem Products, Inc., California Spray-Chemical Company, Dow Chemical Company, Geigy Agricultural Chemicals, Pabst Laboratories, and Upjohn Company.

PROBLEMS AND PRIORITIES

Surveys

Information on the kind, location, and behavior of threatening disease pests is the key to effective control. The Forest Service obtains these essential data through a statewide random sampling of the timber belt, through permanent sample plots on mortality and its causes, and through surveys of specific areas known to harbor troublesome diseases. The improvement of disease survey techniques is a continuing responsibility of research and is so indicated by line project designation.

Acceleration of all types of disease survey will help researchers and forest managers do a better job of forest protection. We are not now meeting the demands of foresters for special surveys on heart rots, root diseases, dwarfmistletoe, "X" disease, and physiological or noninfectious damage. Improved techniques using color aerial photography, sequential sampling, and machine compilation and analysis will help us reach these objectives.

The Station forest disease herbarium is an essential tool of survey, research, and control studies. Many of the collections show both the pathogen, and its characteristic impact on the host tree. Top priority must be given to the maintenance and improvement of this herbarium as a record of survey findings and as a technical aid to researchers, students, and visiting scientists. Unclassified collections now on hand should be identified, documented, and filed and new specimens added.

White Pine Blister Rust

Research and control studies of the past 30 years on the destructive white pine blister rust have provided a sound basis for an effective and economic control program in designated sugar pine management units of commercial forests and in National Park lands. Data from weather records, field plots, greenhouse, and growth chamber studies on the longevity and viability of sporidia indicate that local climate, terrain, and the general pattern of storm movements across California create significantly different zones of rust hazard throughout the sugar pine belt of California. Consequently rust spread will be slow from central California to more southerly forested areas.[3] This conclusion, combined with the possibility of direct treatment of infected pine with antibiotics (as demonstrated for Acti-dione and western white pine in Idaho), has resulted in a revised control policy in low hazard rust areas, that will mean lower control costs. To support this new approach to control of rust on sugar pine, future research should give top priority to:

Improved definition of local rust hazard through studies of the movement, fallout, and viability of both pine-infecting and ribes-infecting spores;

growth rate of established cankers;

development of reliable toxicants and methods for killing blister rust cankers;

improvement of predictions on regeneration and growth rate of ribes;

and improvement in survey techniques to locate new pine infections and to describe ribes populations.

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[3] D. R. Miller. Proposed change in the method of white pine blister rust control for that portion of the Sierra sugar pine belt lying south of Snow Mountain (Lassen National Forest). 1954. 24 pp. (Typewritten)

Dwarfmistletoes and True Mistletoes

The mistletoes rank next to heart rots in statewide growth impact on conifers. Needed studies are:

> To measure mortality, growth loss, and defect attributed to the dwarfmistletoes in commercial forest types and recreation areas of California;
>
> to determine environmental, site, and host factors that control the rate of spread, germination of seed and establishment of infections in the host;
>
> to clarify the host specificity of various forms of *Arceuthobium campylopodum* to pines and firs, especially the cross-over of red fir and white fir forms;
>
> to clarify physiological relationships of host and parasite such as the uptake and exchange of water and mineral nutrients, and the movement of carbohydrate and amino acids and of systemic toxicants between host and parasite;
>
> to test and improve chemical and biological methods for the direct control of the pest;
>
> to search for, test, and propagate individual trees having high natural resistance to the pest.

Decays and Stains

Heart rots alone now account for more than one-third the estimated total annual losses of the forest resource from all disease pests. While losses will decrease as virgin stands are converted to the next crop, we know that fast growing second growth stands are strongly predisposed to rapid development of decay fungi. Under the high investment costs of intensive management we cannot afford to continue losing wood capital at the prevailing rate of about 1/3 billion board feet per year. Further studies on the incidence and development and control of decays and stains should have a high priority in the future program. Top priority is assigned to a study of the prevalence and behavior of heart rot in second growth pine, Douglas-fir, the true fir, and incense-cedar. Principal concern is with *Fomes pini* in Douglas-fir, *Echinodontium tinctorium* and *Pholiota adiposa* in white fir and red fir, *Polyporus amarus* in incense-cedar, *P. schweinitzii* in pines and Douglas-fir, and *Poria sequoiae* in coast redwood.

Lines of research on the incidence and growth rate of major heart rot fungi should be concerned with:

> Effects of temperature, internal gases, enzymes, and natural protective substances in the tree;

the impact of nutrient levels and trace elements on the incidence and growth rate of major heart rot fungi.

These studies should consider the behavior of fungi collected from different geographic areas of the State, so that predictions can be made about their growth rate and external spread from tree to tree. We need to broaden our understanding of the ecology of host tree and heart rot for the commercially important softwoods. Dissection studies of incense-cedar should be extended to parts of California not yet covered. Harvest cuttings should give attention to sanitation measures for all heart rot fungi that consistently produce conks. The question of genetic resistance to several of the major heart rot fungi should be explored, possibly through recently developed and demonstrated serological techniques.

Nursery Diseases

Nursery production in California is increasing sharply because of the emphasis now being given to the rehabilitation of burns, cutover land, and brush fields. As new land is developed for forest nurseries and as seedling and transplant beds are maintained in production, nursery diseases must be kept under constant observation and control measures promptly applied. In nursery production and afforestation, diseases cause loss of seeds, seedlings, and transplants during periods of production, storage, and shipping, and in field planting.

During 1959 severe losses in sugar pine, Douglas-fir, and giant sequoia occurred in the Placerville nursery. *Phytophthora cinnamomi* and *Armillaria mellea* were isolated from damage spots in beds of 2-year-old sugar pine. In the 1-year-old sugar pine and Douglas-fir, two high temperature fungi--*Sclerotium bataticola* and *Fusarium* spp.--were identified and the strong pathogenicity of the former demonstrated. In general, losses from damping-off have not been serious in central and northern California nurseries of the Sierra Nevada.

Research support of the nursery production and planting program should be intensified through:

Identification and experimental proof of pathogenicity of organisms causing losses in the nursery;

development of effective control through cultural and chemical methods;

studies of the cause of mortality in field plantings;

testing of procedures for ensuring disease-free outplanting stock by procedures such as root dips, hot water and other fungistatic treatments.

Root Diseases

Fomes annosus, *Armillaria mellea*, and *Verticicladiella* sp. are the most prevalent and damaging root disease fungi in California forests. *F. annosus* has by far the greatest impact statewide and is most active on ponderosa and Jeffrey pine under eastside Sierra Nevada and southern California conditions. Trees of all sizes are attacked. This fungus is particularly aggressive in young trees adjacent to old pine stumps. *F. annosus* does not often produce conks under California's climatic conditions. Those that are produced are usually under the duff so that most of the spread of this fungus is through contact of healthy and diseased roots. Insects may spread the disease but the extent of their activity is indeterminate.

Losses from *F. annosus* are cyclic; they are most noticeable 3 to 5 years after unusually wet years. The fungus apparently is more active in loose soils than in heavy ones. As the amount of cutover forest land increases and as more frequent thinnings are made, we can expect increased losses from this root disease. Pathologists generally agree that annosus and other root diseases tend to increase under monoculture.

Armillaria, though widespread in the State, is generally much less destructive than *F. annosus* and is often associated with oak stumps and their decaying roots.

So far *Verticicladiella* damage has been found on ponderosa and Jeffrey pine in a few locations on the Lassen and Modoc National Forests and on pinyon pine around Baldwin Lake in San Bernardino County. *Verticicladiella* is probably more widespread in ponderosa and Jeffrey pine than is now realized. Activity of this fungus and the damage that it causes is often masked by bark beetle invasion.

Where spread takes place from fruiting bodies some measure of control of *F. annosus* and other root diseases can be obtained through treatment of freshly cut stumps with creosote. In areas of intensive use or in valuable plantations, mechanical eradication of all roots and soil treatment with methyl bromide, mixtures of chloropicrin and methyl bromide, and other soil fumigants are the only reliable methods of control. These treatments are used in Europe but at present would seem to be economically feasible in California only in arboreta, parks, and other intensively used areas.

Further research on *Fomes annosus* has high priority and should include:

Special attention in the survey program to locate new infection centers and to correlate the incidence of infection with site, soil type, and abnormal soil moisture conditions;

determination of how long *F. annosus* remains viable following invasion in roots of different sizes and in stumps of ponderosa and Jeffrey pines;

role of biological control or competition from organisms such as Trichoderma spp. and their activity under variable conditions of soil pH and aeration;

testing and development of improved chemical methods for spot treatment of infection centers;

search for genetically resistant individuals;

joint study with entomologists of the role of insects in spreading the disease to cut stumps; isolation of F. annosus from common heart rot of red fir or white fir and cross inoculation of roots of Jeffrey pine to see if some strains of the fungus behave as a heart rot and root rot.

Genetic Resistance

The development of blister rust resistant sugar pine has been an established and going job since 1949. Basic work plans and the contributions and responsibilities of cooperating agencies have been clearly set forth (5). Objectives include: the search for and initial certification of candidate sugar pine trees; propagation and testing of rust resistant selections; the development of archive plantations and seed orchards; and the development and testing of interspecific hybrids. Ten annual progress reports on the sugar pine project have been made from 1951-1960; they are included in processed reports compiled by the Forest Service, Washington, D. C. To date we can report briefly the following accomplishments:

Rust resistant candidate trees located, 92;

total grafts outplanted, 300;

additional grafts made in 1960, 560;

development of outplanting sites for grafts and hybrids, 2.

Preliminary tests of rust resistance in ponderosa pine were made at Placerville in 1948-53 by pathologists and geneticists. They used selections of ponderosa pine to compare the response of open and control pollinated seedlings to artificial exposures to the gall rust Peridermium harknessii. Additional exposure tests of known progeny of ponderosa pine will be made by pathologists and geneticists in 1961.

Studies of blister rust and gall rust provide considerable evidence that individual conifers exhibit strong resistance to attacks by diseases.

Pathologists must work with geneticists, silviculturists, and entomologists in establishing the value of elite trees and hybrids in afforestation. Search for candidate trees and resistance tests should be extended to diseases other than blister rust. Of particular interest to the disease research program are studies on the physiological nature of disease resistance aimed at developing biological or chemical tests that would shortcut the present slow and expensive methods of propagating and testing seed progeny. Serological techniques offer promise in this field of research. In support of disease research and other practical problems in tree improvement for disease resistance, geneticists and physiologists should accelerate tests on reliable and inexpensive methods for the vegetative propagation of naturally resistant individuals, on the improvement in techniques for grafting, and on the induction of early flowering.

Noninfectious and Unknown Disorders, ("X" Disease)

Adverse environmental factors plus the impact of diseases combine to create a condition of stress and tension in coniferous forests of southern California and other parts of the mixed conifer type. Variable and deficient moisture, air pollutants, deficient or pathogenic soil flora, and intensive use by people and animals contribute to this condition of stress in forest stands. "X" disorder of ponderosa pine in southern California is a prime example of this problem.

Forest disease research in this problem area represents just part of the needs. A team approach enlisting the help of a plant physiologist, a soil biologist, a meteorologist, and an entomologist is recommended. Station and University of California pathologists should accelerate research and control studies as follows:

> Intensify survey to find out where and how much of this "X" disease occurs in southern California forests;
>
> determine fungi responsible for observed rootlet mortality;
>
> identify and study soil moisture and temperature, air pollutants and biological factors other than root fungi that contribute to the general tension of the affected area;
>
> start direct experimental control on test plots with watering and fertilizing including additions of heavy metal chelate salts such as iron, manganese, zinc, etc.

Miscellaneous Diseases

Many other diseases and defects take an annual toll of our wildland resource or forest products and are receiving some attention from survey and research personnel. Some of these problems are being studied by the Forest Products Laboratory, the Intermountain and Pacific Northwest Forest Experiment Stations, and are not now being emphasized here. All of the problems in the list that follows are of concern to the forest pathologist because changes in management objectives and cyclic trends in the weather may require changes of emphasis in program planning.

a. *Elytroderma deformans* (needle blight). Studies in progress at Pacific Northwest and Intermountain Stations, Oregon State College, Montana University, and Weyerhaeuser Timber Company should supplement our present knowledge of the ecology and control of this fungus. At the Pacific Southwest Station tests are being made on effects of antibiotics and other systemic fungicides for the control of *Elytroderma*. Foliage diseases of true firs and Douglas-fir merit close watch because of their importance in the Christmas tree trade.

b. The incidence and development of stain fungi in fire-killed and insect-killed timber. Pathologists and entomologists need to identify fungi associated with the staining of killed timber and to clarify the role of insects, which largely determine the spread of stain organisms; data are needed on rate of spread of stain fungi in relation to site, local climate, time of year when fire occurs, and tree species.

c. Yellow witches' broom (*Melampsorella caryophyllacearum*) of red fir. Tests of spot control of chickweeds are proposed as a check on distance of spread. Further data are needed on epidemiology of this fungus.

d. Unknown stem canker of ponderosa pine, possibly atypical gall rust or comandra rust. When aecia can be obtained, inoculation tests are proposed for possible alternate host plants. The development of successful tissue culture would greatly facilitate studies of such unknown pathogens. More information is needed on the epidemiology of the cytospora canker of true firs and the phomopsis canker of Douglas-fir.

e. Epidemiology of a species or form of *Coryneum* that has damaged redwood plantations and redwood sprouts (63). The causal fungus seems to be closely related to the well-known *Coryneum* which has killed thousands of planted Monterey cypress.

f. Establish the perfect stage of the *Verticicladiella* spp. root fungus.

g. Unidentified decay in heartwood of giant sequoia. Is this *Poria sequoiae* that occurs in coast redwood? Determine from culture the identity of the common white pocket rot of Port Orford cedar suspected to be *Fomes nigrolimitatus*. Also an unidentified stringy decay of the butts of sugar pine.

h. Dieback of bitterbrush *Purshia tridentata*. Is this the result of weakly parasitic root fungi?

i. Littleleaf formation and suppression in bigleaf maple. Is this a virus?

j. Identify the canker of incense-cedar, a weakly pathogenic fungus that attacks incense cedars weakened from drought or cold.

k. Determine cause of a "wetwood" disease of pines.

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LIST OF ACTIVE STATION PROJECTS

Summaries of the status and needed research for all line projects in Forest Disease Research at the Pacific Southwest Forest and Range Experiment Station were prepared as a supplement to this program analysis. Project summaries were first outlined by the personnel named in the following list. Project reports were then revised to make them uniform in format and to utilize ideas and references of the program analysis. Copies of these project summaries will be filed according to project title and number and are available on request. As new ideas or information become available, each member of the staff deposits addenda in the appropriate file so that research ideas and objectives can be kept up to date and vital.

Foliage diseases	FS-2-d1-1-PSW	(Bega)
Rusts of conifers	FS-2-d1-2-PSW	(Quick)
Cankers	FS-2-d1-3-PSW	(Paine)
Dwarfmistletoes	FS-2-d1-5-PSW	(Scharpf)
Stains and decays	FS-2-d1-6-PSW	(Paine)
Root diseases	FS-2-d1-7-PSW	(Bega)
Noninfectious diseases	FS-2-d1-8-PSW	(Wagener)
Slash decay	FS-2-d1-10-PSW	(Wagener)
Genetic resistance	FS-2-d1-11-PSW	(Quick)
Nursery diseases	FS-2-d1-12-PSW	(Bega)
Unknown diseases	FS-2-d1-13-PSW	(Bynum)
Disease survey techniques	FS-2-d2-1-PSW	(Miller)
Decay of killed timber	FS-2-d3-1-PSW	(Wagener)

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